

Decay of Charged Higgs boson in TeV scale supersymmetric seesaw model

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Abstract. We discuss phenomenological consequences of some class of supersymmetric seesaw models in which the right-handed (s)neutrino mass is given to be TeV scale. In this scenario, scalar trilinear interaction of Higgs-slepton-(right-handed) sneutrino is enhanced. We show that the 1-loop correction by sneutrino exchange to the lightest Higgs boson mass destructively interferes with top-stop contributions in the minimal SUSY Standard Model. We find that a decay of charged Higgs boson into sneutrino and charged slepton is sizably enhanced and hence it gives rise to a distinctive signal at future collider experiments in some parameter space.

PACS. 12.60.Jv Supersymmetric models – 14.80.Cp Non-standard-model Higgs bosons

1 Introduction

The seesaw mechanism [1] is one of the most attractive explanation of small neutrino masses. The heavy right-handed neutrinos are introduced in the seesaw mechanism, and resulting small neutrino mass eigenvalues is given by $m_\nu \simeq (Y_\nu v)^2/m_N$, where m_N and v are the mass of right-handed neutrino and the vacuum expectation value (v.e.v.) of the Higgs boson, respectively. To explain the smallness of m_ν , the right-handed neutrino mass m_N should be much more larger than electroweak scale if the Yukawa coupling Y_ν is close to order unity. Therefore, we cannot hope to test the seesaw mechanism through searching for the right-handed neutrino at collider experiments. Thus it is reasonable to consider a possibility to lower the scale of seesaw mechanism (scale of right-handed neutrino mass) as low as testable at collider experiments.

It has been discussed such possibilities to explain the small neutrino mass as a consequence of supersymmetry (SUSY) breaking in refs. [2, 3, 4]. The phenomenological aspects of this class of models can be summarized as follows : (i) light (TeV scale) right-handed sneutrino due to the Giudice-Masiero mechanism [5] and (ii) enhancement of scalar trilinear interaction among the right-handed sneutrino, left-handed slepton and Higgs bosons. In the minimal SUSY SM (MSSM), the scalar three-point vertices are suppressed by small Yukawa couplings for the first two generations of squarks and sleptons. In the models of refs. [2, 3, 4], however, the scalar trilinear interaction of the right-handed sneutrino is not suppressed by the neutrino Yukawa coupling, as mentioned above.

In this work [6], we investigate phenomenological consequences of a scenario of TeV scale right-handed sneutrino inspired by supersymmetric models in refs. [2, 3, 4], focusing on the unsuppressed coupling A_ν . We first study the 1-loop corrections to the lightest Higgs boson mass through the sneutrino exchange which is proportional to some powers of A_ν . We show that the sneutrino contribution destructively interferes with the MSSM contribution. We next study decay processes of charged Higgs boson [2]. The decay of charged Higgs boson into the sneutrino and selectron could be enhanced as compared to the MSSM because of A_ν . We find that, in some parameter space, the branching ratio of this decay mode can be as large as 10%, and it may be detectable at future linear collider experiments. Although this scenario has a possibility if the neutrino is Majorana or Dirac [3, 7], our study is available in both cases if the SUSY breaking B -term of sneutrino in the Majorana case is assumed to be small enough so that, in addition to suppress the 1-loop correction to the mass of lighter neutrino, the sneutrino mass matrix has common structure in both cases.

2 Sneutrino mass spectrum

We first show the sneutrino mass spectrum for later convenience. When the SUSY breaking B -term of sneutrino is neglected, the mass matrix of sneutrinos in a basis of $(\tilde{\nu}_L, \tilde{\nu}_R)$ is given by

$$M_{\tilde{\nu}}^2 = \begin{pmatrix} m_{\nu_L}^2 & A_\nu v \sin \beta \\ A_\nu v \sin \beta & m_{\nu_R}^2 \end{pmatrix}, \quad (1)$$

$$m_{\nu_L}^2 = m_L^2 + \frac{1}{2} \cos 2\beta m_Z^2, \quad (2)$$

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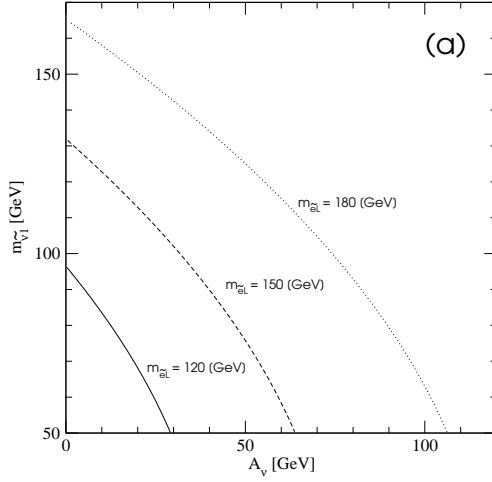


Fig. 1. The lighter sneutrino mass $m_{\tilde{\nu}_1}$ as a function of A_ν for $\tan\beta = 3$. Three lines correspond to $m_{\tilde{e}_L} = 120\text{GeV}$ (solid), 150GeV (dashed) and 180GeV (dotted). The results are obtained by taking $m_{\tilde{\nu}_L}^2 = m_{\tilde{\nu}_R}^2$.

where m_L is the soft scalar mass for the $SU(2)_L$ doublet slepton while $m_{\tilde{\nu}_R}$ is for the right-handed sneutrino. We neglect the generation mixings the whole this work. The angle β is defined as $\tan\beta \equiv v_u/v_d$, where v_u and v_d are v.e.v. of the Higgs bosons with $Y = 1/2$ and $-1/2$, respectively. A parameter v is normalized as $v \equiv \sqrt{v_u^2 + v_d^2} \approx 246\text{GeV}$. The mass matrix (1) can be diagonalized using an unitary matrix $U_{\tilde{\nu}}$:

$$(U_{\tilde{\nu}})^\dagger M_{\tilde{\nu}}^2 U_{\tilde{\nu}} = \text{diag}(m_{\tilde{\nu}_1}, m_{\tilde{\nu}_2}), \quad (m_{\tilde{\nu}_1} < m_{\tilde{\nu}_2}). \quad (3)$$

In the MSSM, the sneutrino mass is given by (2). Note that $m_{\tilde{\nu}_L}^2$ (2) satisfies the following relation with the mass of left-handed selectron \tilde{e}_L due to the $SU(2)_L$ symmetry: $m_{\tilde{e}_L}^2 - m_{\tilde{\nu}_L}^2 = (-1 + s_W^2)m_Z^2 \cos 2\beta$. Since $\cos 2\beta < 1$ for $\tan\beta > 1$, the mass of sneutrino in the MSSM is always smaller than the selectron mass when $\tan\beta > 1$. On the other hand, the lighter sneutrino mass (3) is independent of the selectron mass and can be much lighter than the sneutrino in the MSSM.

In Fig. 1(a), we show the lighter sneutrino mass $m_{\tilde{\nu}_1}$ as a function of A_ν for $\tan\beta = 3$. Three lines correspond to $m_{\tilde{e}_L} = 120\text{GeV}$ (solid), 150GeV (dashed) and 180GeV (dotted). For the right-handed sneutrino mass, we take $m_{\tilde{\nu}_R} = m_{\tilde{\nu}_L}$ for convenience. Note that the mass $m_{\tilde{\nu}_1}$ at $A_\nu = 0$ corresponds to that in the MSSM. The figure tells us that the large left-right mixing of sneutrino which is induced by large A_ν , makes a sneutrino much lighter than that in the MSSM.

3 Sneutrino contribution to the lightest Higgs boson mass

The lightest Higgs boson mass m_h receives large 1-loop corrections mainly from the top quark and the

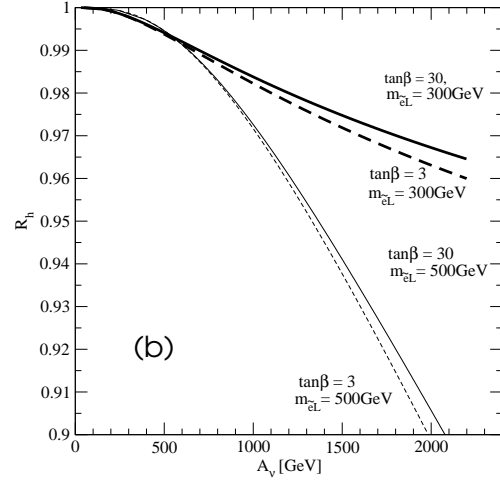


Fig. 2. The ratio R_h defined as $R_h \equiv m_h/m_h(\text{MSSM})$ as a function of A_ν . Each line correspond to combinations of $\tan\beta = 3, 30$ and $m_{\tilde{e}_L} = 300, 500\text{GeV}$ as indicated. The 1-loop correction from the top-stop loop is evaluated following ref. [12] using the stop mass $m_{\tilde{t}} = 1\text{TeV}$. The Higgs mass m_h at $A_\nu = 0$ corresponds to the MSSM prediction.

stop exchanging diagram [8,9,10]. In the scenario of TeV scale $\tilde{\nu}_R$ mass with sizable A_ν , the $\tilde{\nu}_L$ - $\tilde{\nu}_R$ - h interaction could give a new contribution to the lightest Higgs boson mass at 1-loop level. Using the renormalization group method used in ref. [9], we evaluate the sneutrino contribution to m_h .

Let us take the large limit of the SUSY breaking mass scale m_{SUSY} so that physics below m_{SUSY} is described by the Standard Model. Then the lightest Higgs boson mass m_h is simply parametrized by $m_h^2 = \lambda v^2$, where λ is a quartic coupling in the Higgs potential. Note that the quartic coupling at the tree level, λ_{tree} , satisfies the SUSY relation $\lambda_{\text{tree}} = (g_Y^2 + g^2) \cos^2 2\beta/4$, where g_Y and g are the $U(1)_Y$ and $SU(2)_L$ gauge couplings, respectively. The radiative corrections to the quartic coupling λ in the MSSM can be found in, for example, ref. [9]. In the scenario of large A_ν , the interaction $\tilde{\nu}$ - $\tilde{\nu}$ - h gives rise to the sneutrino exchanging box diagram as the 1-loop correction to the quartic coupling λ . The sneutrino contribution, $\lambda_{\tilde{\nu}}$, can be evaluated as

$$\lambda_{\tilde{\nu}} = -\frac{A_\nu^4}{4(4\pi)^2} \sum_{i,j,k,l=1}^2 |U_{1i}^{\tilde{\nu}}|^2 |U_{2j}^{\tilde{\nu}}|^2 |U_{1k}^{\tilde{\nu}}|^2 |U_{2l}^{\tilde{\nu}}|^2 \times D_0(m_{\tilde{\nu}_i}, m_{\tilde{\nu}_j}, m_{\tilde{\nu}_k}, m_{\tilde{\nu}_l}), \quad (4)$$

where D_0 is the 1-loop scalar function.

We compare, in Fig. 2, a ratio of the Higgs boson mass in our scenario and in the MSSM which is defined as $R_h \equiv m_h/m_h(\text{MSSM})$, where m_h and $m_h(\text{MSSM})$ are the lightest Higgs boson mass in our scenario and the Higgs mass in the MSSM, respectively. In the figure, the 1-loop corrections in the MSSM are estimated following ref. [12] with the stop mass $m_{\tilde{t}} = 1\text{TeV}$. Solid and dotted lines denote $m_{\tilde{e}_L} = 300\text{GeV}$ and 500GeV , respectively. Thin and thick lines are $\tan\beta = 3$ and 50

as indicated in the figure. Note that R_h at $A_\nu = 0$ correspond to the MSSM prediction. It is easy to see that R_h (and m_h) decrease when A_ν increases. This means that the sneutrino contribution to m_h interferes with the MSSM contributions destructively. For example, in a limit where two sneutrino masses are equal (m_{SUSY}), the quartic coupling λ_ν is given as

$$\lambda_\nu \simeq -\frac{1}{6} \frac{1}{(4\pi)^2} \left(\frac{A_\nu}{m_{\text{SUSY}}} \right)^4 < 0. \quad (5)$$

The minus sign in r.h.s. of (5) is the origin that m_h is lowered via the sneutrino contribution. Fig. 2 shows that the negative contribution to m_h from the sneutrino diagram is less than 5% for $A_\nu \lesssim 1\text{TeV}$.

4 Decay of charged Higgs boson

We next examine a decay $H^- \rightarrow \tilde{\nu} + \tilde{\ell}$, where H^- stands for a charged Higgs boson. In particular, a case of $\tilde{\ell} = \tilde{e}$ could be a distinctive process of our scenario because that such process is strongly suppressed in the MSSM due to the electron Yukawa coupling. So, we consider only the case of $\tilde{\ell} = \tilde{e}$ in the following study. In the MSSM, it is known that, for $m_{H^-} \gtrsim 200\text{GeV}$, H^- dominantly decays into the top and bottom quarks owing to the sizable Yukawa couplings (for a review of various decay channels of the charged Higgs boson in the supersymmetric models, see ref. [11]). The $\tau + \nu_\tau$ mode is subdominant for large $\tan\beta$ ($\gtrsim 10$) due to the tau-Yukawa coupling. On the other hand, when A_ν is sizable, it is expected that the decay mode $H^- \rightarrow \tilde{\nu}_1 + \tilde{e}$ is much enhanced in small $\tan\beta$ region because that the decay vertex is proportional to $A_\nu \cos\beta$.

In Fig. 3, we show branching ratios of some decay modes of the charged Higgs boson with $m_{H^-} = 350\text{GeV}$ as functions of $\tan\beta$. We assume that squarks are heavy enough so that the decay modes into squarks are kinematically forbidden. Heavy squarks are also favored to make the lightest Higgs boson heavy through the radiative corrections, against for the negative contribution to m_h from the sneutrino exchanging diagrams. The sneutrino and selectron masses are chosen as $m_{\tilde{\nu}_1} = 50\text{GeV}$ and $m_{\tilde{e}_L} = 200\text{GeV}$, respectively. The trilinear coupling of right-handed sneutrino A_ν is fixed at 500GeV . Then the heavier sneutrino mass ($m_{\tilde{\nu}_2}$) is about 700GeV . As already mentioned, we assumed the flavor universality of A_ν , so the branching ratio of decay into the sneutrino and smuon, or stau, is same with the selectron mode shown in the figure. As an example, the branching ratio of decay into charginos ($\tilde{\chi}_i^\pm, i = 1, 2$) and neutralinos ($\tilde{\chi}_j^0, j = 1, 4$) is examined for $m_{\tilde{\chi}_1^\pm} = 150\text{GeV}$ with $M_2/\mu = 5$ in Fig. 3(a) and $M_2/\mu = 1$ in Fig. 3(b), where M_2 and μ stand for the $\text{SU}(2)_L$ gaugino mass and the higgsino mass, respectively. The $\text{U}(1)_Y$ gaugino mass M_1 is obtained using the GUT relation, $M_1/\alpha_Y = (5/3)(M_2/\alpha_2)$, where $\alpha_i (i = Y, 2)$ are given as $\alpha_i = g_i^2/(4\pi)$. Then the mass of lightest neutralino is given

as $m_{\tilde{\chi}_1^0} \sim 142\text{GeV}$ in Fig. 3(a) and 93GeV in Fig. 3(b).

The ratio M_2/μ determines the properties of the lighter chargino and the lightest neutralino. When $M_2/\mu \ll 1$ the lighter chargino is mostly the $\text{SU}(2)_L$ gaugino while the relation $M_2/\mu \gg 1$ corresponds to the higgsino dominant case. For $M_2/\mu = 5$, both the lighter chargino and the lightest neutralino are higgsino dominant, so that the decay $H^- \rightarrow \tilde{\chi}_1^- + \tilde{\chi}_1^0$ is highly suppressed because there is no Higgs-higgsino-higgsino coupling. This explains the difference of $\text{Br}(H^- \rightarrow \tilde{\chi}_1^- + \tilde{\chi}_1^0)$ between Figs. 3(a) and (b).

It can be seen from Fig. 3 that the branching ratio of $H^- \rightarrow \tilde{\nu} + \tilde{\ell}$ mode could be as large as 10% for small $\tan\beta$ ($\lesssim 7$). In the MSSM, the charged Higgs boson can decay into $\tilde{\nu}_L$ and \tilde{e}_R . For comparison, we fix the mass of \tilde{e}_R as $m_{\tilde{e}_R} = m_{\tilde{e}_L} = 200\text{GeV}$. Then the decay mode $H^- \rightarrow \tilde{\nu}_L + \tilde{e}_R$ is kinematically forbidden because the sneutrino $\tilde{\nu}_L$ cannot be much lighter than \tilde{e}_L due to the $\text{SU}(2)_L$ relation (note that $m_{\tilde{e}_R} = m_{\tilde{e}_L} = 200\text{GeV}$). Therefore, if the charged Higgs boson mass does not differ so much from the masses of charged sleptons, the decay $H^- \rightarrow \tilde{\nu}_L + \tilde{e}_R$ in the MSSM is strongly suppressed.

Next we study a signal of the decay $H^- \rightarrow \tilde{\nu}_1 + \tilde{e}_L$ in some detail. For our choice of the inputs used in Fig. 3, the selectron \tilde{e}_L dominantly decays into the lightest neutralino and an electron, $\tilde{e}_L \rightarrow \tilde{\chi}_1^0 + e$. Then, since the branching ratio of the $\tilde{\nu}_1 + \tilde{e}_L$ mode is roughly 10% for small $\tan\beta$ region, a probability which we find an electron from this decay mode can be estimated as $\text{Br}(H^- \rightarrow \tilde{\nu}_1 + \tilde{e}_L) \times \text{Br}(\tilde{e}_L \rightarrow e + \tilde{\chi}_1^0) \simeq 10\%$. The electron is also coming out from the W boson of the decay $H^- \rightarrow W + h$, and the chargino of the decay $H^- \rightarrow \tilde{\chi}^- + \tilde{\chi}^0$. From Fig. 3 we find that $\text{Br}(H^- \rightarrow W + h) \lesssim 3\%$ and the leptonic decay of the W boson is known as $\text{Br}(W \rightarrow \nu + e) \lesssim 10.8\%$ [13]. It leads to $\text{Br}(H^- \rightarrow W + h) \times \text{Br}(W \rightarrow \nu + e) \lesssim 0.3\%$. In case of Fig. 3(a), therefore, the background from $H^- \rightarrow W + h$ is much suppressed. In case of $H^- \rightarrow \tilde{\chi}^- + \tilde{\chi}^0$, the branching ratio is $\text{Br}(H^- \rightarrow \tilde{\chi}^- + \tilde{\chi}^0)$ is about 1% and $\text{Br}(\tilde{\chi}^- \rightarrow e + \tilde{\nu})$ is roughly 30% per each lepton flavor. Thus $\text{Br}(H^- \rightarrow \tilde{\chi}^- + \tilde{\chi}^0) \times \text{Br}(\tilde{\chi}^- \rightarrow e + \tilde{\nu})$ is about 0.3%.

As shown in Fig. 3(b), however, if the lighter chargino is dominantly gaugino, the branching ratio of the chargino-neutralino mode increases, so that the branching ratio of $H^- \rightarrow \tilde{\nu}_1 + \tilde{e}_L$ is relatively decreased. In this case we estimate the probability that the electron is found in the $\tilde{\chi}^- + \tilde{\chi}^0$ mode of the charged Higgs decay as $\text{Br}(H^- \rightarrow \tilde{\chi}^- + \tilde{\chi}^0) \times \text{Br}(\tilde{\chi}^- \rightarrow e + \tilde{\nu}) \simeq 10\%$. This competes with the probability that an electron is coming out from the $\tilde{e}_L + \tilde{\nu}_1$ decay. We conclude that, even in our specific choice of parameter set, the $\tilde{\chi}^- + \tilde{\chi}^0$ mode could be a serious background to search the decay $H^- \rightarrow \tilde{\nu}_1 + \tilde{e}_L$ when the chargino and neutralino are almost gauginos.

We would like to discuss the testability of the scenario of light $\tilde{\nu}_R$ with unsuppressed A_ν at future collider experiments using the decay $H^- \rightarrow \tilde{\nu}_1 + \tilde{e}_L \rightarrow e + \cancel{ET}$. An important point is to identify that the observed

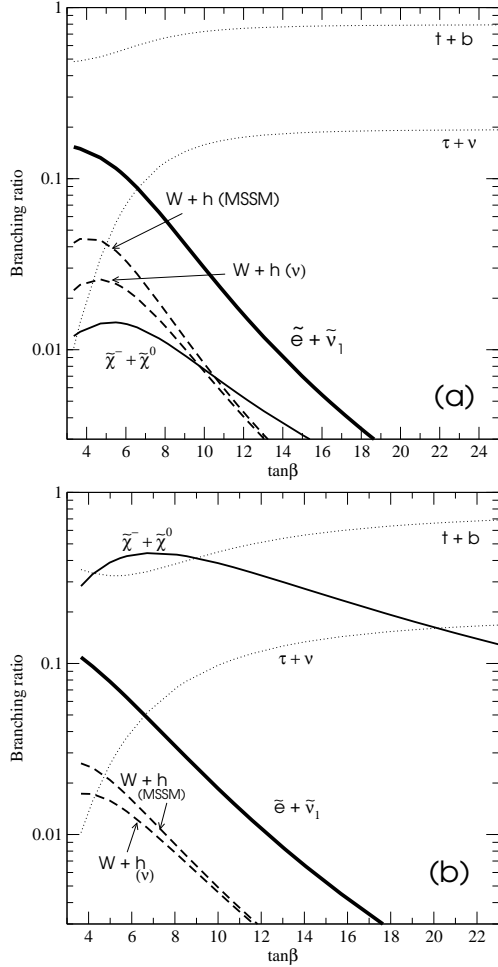


Fig. 3. The branching ratios of charged Higgs boson decay for $m_{H^-} = 350\text{GeV}$. The decay mode into sneutrino and selectron is found for $m_{\tilde{e}_L} = 200\text{GeV}$, $m_{\tilde{\nu}_1} = 50\text{GeV}$, $A_\nu = 500\text{GeV}$. The chargino-neutralino mode is obtained for $m_{\tilde{\chi}_1^-} = 150\text{GeV}$ with $M_2/\mu = 5$ (a) and 1 (b).

electron comes from H^- . It could be achieved using the pair production of the charged Higgs bosons. In a pair production of the charged Higgs, one of the charged Higgs bosons can be identified using the $t + b$ mode. Then if an electron is observed in the charged Higgs pair production it must be identified as one from the decay of another charged Higgs through $H^- \rightarrow \tilde{\nu}_1 + \tilde{e}_L$. For example, at the e^+e^- linear collider (ILC), the typical size of the cross section of the charged Higgs boson pair is $O(1 - 10)(\text{fb})$ for $m_{H^-} = O(100\text{GeV})$ [11]. Assuming the integrated luminosity as 100fb^{-1} , it is expected that $100 \sim 1000$ charged Higgs pairs are produced in a year. Fig. 3(a) tells us that, when $\tan\beta = 3$, only few electrons appear from 1000 charged Higgs bosons in the MSSM (the $W + h$ mode), while about 160 electrons from the $\tilde{e} + \tilde{\nu}_1$ mode is expected in our scenario. Therefore, an excess of electrons from the charged Higgs decay could be a signal of the TeV scale right-handed sneutrino with unsuppressed trilinear coupling A_ν .

5 Summary

In this work, we have studied phenomenology of the scenario of TeV scale right-handed sneutrino inspired by models of SUSY breaking inspired neutrino mass [2, 3, 4]. The important prediction of this scenario is that the sneutrino trilinear coupling A_ν could be sizable and is not suppressed by the neutrino Yukawa coupling. We found that the sneutrino contribution to the lightest Higgs boson mass is destructively interferes with the ordinary MSSM contributions and may be lowered in this model via sneutrino exchange with large A_ν . The large A_ν also affects the decay of charged Higgs boson. It is shown that the process $H^- \rightarrow \tilde{\nu}_1 + \tilde{e}_L$ could be subdominant decay mode in some parameter region and the branching ratio is roughly $\sim 10\%$ for small $\tan\beta$. In such parameter region, the excess of the electrons in the charged Higgs decay could be a signal of the TeV $\tilde{\nu}_R$ scenario.

6 Acknowledgments

The work was supported by the Japan Society of Promotion of Science, by European Commission Contracts No. MRTN-CT-2004-503369.

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